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production. Optimization methods are used in chemical food formulations.

There is a very close relationship between neural networks and fuzzy systems, because both work with some degree of imprecise information, in a non-well-defined space without clear and deterministic limits. In fact, a bidirectional relationship can be established between fuzzy logic and neural networks, since it is possible to use neural networks as membership functions, or to optimize certain parameters in fuzzy systems. However, fuzzy logic systems can be used to model neurons specialized in the processing of vague or ambiguous information.

Probabilistic reasoning. This section discusses only one aspect of probabilistic reasoning: genetic algorithms. These are searching techniques based on biological principles supported by the theory of evolution (that is, the survival of the fittest). In the 1970s, John Holland established the basis of genetic algorithms as a process able to emulate nature. The main objectives were to design artificial systems software with the capacity to incorporate the important mechanisms of biological systems and to explain the adaptive processes of natural systems.

Genetic algorithms turn a population of individuals, according to a fitness function (indicating how strong an individual is with respect to others), into a new population. Chromosomes are represented in computers by chains of bits. Each individual (or chromosome) in a population represents a possible solution to a problem. To solve a problem, a solutions space search is needed, using information that leads to the desired objective. The most apt individual in a population is the one with the greatest ability to find the solution to a given problem. A practical genetic algorithm is based on three operators. Reproduction is a process where individual strings are copied, based on how good they are with respect to the others. Crossover allows the creation of new individuals from the mating of two parents. Mutation allows the introduction of information not present in the population. The parameters to control genetic algorithms are the size of the population and the maximum number of generations (called a run). Every genetic algorithm run requires the specification of a completion criterion and a designation method to determine when to stop it. Each new generation is an approach toward the solution of the problem at hand.

Genetic algorithms are used in areas of optimization, machine learning, automatic programming, economy, ecology, and social systems. In optimization they are used for function optimization, the traveling agent problem, image processing, job shop scheduling, and control systems. In machine learning they are used to syntactically learn a set of simple IF-THEN rules, as well as to generate weights for neural networks, rules for classification systems, symbolic production systems, and sensors for robots.

Smart future. Smart devices in the future will have high machine intellectual quotients (MIQ) and will be completely different from present intelligent machines. There will be small and fast computers, and the huge systems and networks also will become smart. Machines will be reduced in size, have finer sensors and signal processors, and be able to generate their own fuzzy rules, based on their own experience.

For background information *see* ARTIFICIAL INTELLIGENCE; AUTOMATION; FUZZY SETS AND SYSTEMS; GENETIC ALGORITHMS; HUMAN-MACHINE SYSTEMS; INTELLIGENT MACHINE; NEURAL NETWORK; ROBOTICS in the McGraw-Hill Encyclopedia of Science & Technology.

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Soil erosion reduction

The human population may double by midcentury. Coupled with improved living standards in underdeveloped nations, this growth will demand unprecedented increases in agricultural production. The great threat to meeting these needs is decreased crop productivity caused by soil erosion. Agricultural productivity and production value are highest in irrigated arid areas, which tend to have shallow, highly erodible soils. Thus, the agricultural systems most capable of meeting future needs are also the most threatened by erosion. Developing effective erosion control methods to protect the sustainability of the Earth's soil is of utmost importance.

Erosion processes. Erosion results from the interaction of fluids (air and water) and soil. Erosion process mechanics involve the transfer of fluid kinetic energy to soil and the resulting detachment, transport, and deposition of soil particles. Wind causes about one-third and water two-thirds of all erosion. Which type dominates depends on the climate, landscape, and land ecology and management. Wind and water erosion control techniques share many soil and land management principles, especially maintaining surface roughness and anchoring or protecting soil with vegetation, organic residues, or other amendments. Catastrophic erosion occurs more commonly with water than wind.

Eroding water originates as precipitation (including snow-melt) or irrigation. Erosion cannot initiate detachment without kinetic energy from waterdrop impact or shearing runoff flow. The ease of detachment is influenced by soil and water chemical and physical properties, which affect soil particle cohesion and kinetic energy transfer. Transport cannot occur without runoff. Consequently, nearly all erosion prevention methods depend on soil structure stabilization, armoring, and prevention or management of the runoff volume or velocity. Deposition occurs when the runoff energy decreases, either because of reduced flow velocity or because of reduced flow volume due to infiltration or decreased inflow.

Control methods: rain-fed versus irrigation agriculture. Erosion control in rain-fed agriculture includes tillage to increase surface roughness or infiltration; strip tillage; reduced tillage and no-tillage to preserve surface vegetative residue; slope and slope-length reduction via terracing, contour cropping, intercropping, and narrow rows to provide canopy coverage; grassed waterways; tile drainage; and preserving soil organic matter to promote earthworms and aggregation, which create macropores and reduce runoff. Many of these erosion control approaches can be used in irrigated agriculture as well. However, although erosion processes are identical for water from precipitation or irrigation, the process dynamics and interaction of the process components differ between precipitation- and irrigation-induced erosion. These differences stem from soil and water chemistry interactions, wetting rates, splash rates, applications, and infiltration patterns. The effects of these differences vary greatly among irrigation types.

Some important differences between precipitation- and irrigation-induced erosion are easily identified. Water with high electrical conductivity or a high ratio of dissolved calcium to sodium salts aids interparticle attractions, cohesion, and flocculation, reducing particle detachment and dispersion. Conversely, the absence of electrolytes or the dominance of sodium ions (lower charge and larger hydrated radius than calcium ion) disperses particles, facilitating detachment and increasing erosion. Nonsprinkler irrigation has no splash energy to detach soil. In precipitation-induced erosion, the soil is wet before runoff begins and the runoff volume accumulates downslope. In furrow irrigation, hot dry soil is instantly hydrated by inflow and infiltration decreases the runoff volume downslope.

Various means of reducing erosion have been developed that are unique to irrigation, such as managing the physical application of water to the soil (for example, by using small close-spaced furrow streams; sprinkling with smaller drops, reducing runoff; and using precise scheduling and volume application control to prevent overirrigation). The irrigation water's electrolyte chemistry can be adjusted to overcome salt effects or to adjust the ratio of specific cations. This is done by adding calcium salts (such as gypsum) or by blending water from multiple sources (conjunctive water use).

Polyacrylamides. Among the newest and most successful erosion control technologies for irrigation is the use of natural and synthetic polymers in irrigation water. Acid cheese whey, chitosan (shellfish by-product) compounds, emulsified cellulose microfibrils, and ultrahigh-molecular-weight synthetic polymers, particularly water-soluble polyacrylamide (PAM), are effective. PAM, currently the most economical of these polymers, reduces erosion 94% in furrow irrigation and 75% in sprinkler irrigation. High efficacy, low cost, and easy application led to successful PAM use on a million United States acres in 1999. Use in the United States and elsewhere is growing rapidly. PAM formulations vary greatly, depending on molecular weight, conformation, functional group substitutions, charge type, and charge density. The PAMs used for erosion control encompass only water-soluble, noncrosslinked (linear) PAMs, and not gel-forming superwater-absorbent, crosslinked PAMs. Application cost plus environmental and human hygiene considerations have limited erosion-control PAMs to anionic formulations of 4–15 mg per mole. Research suggests that 12–15 mg per mole compounds are the most effective for erosion control.

Anionic PAMs bind anionic soil particles by bridging with cations of small hydrated radius, particularly divalent calcium cation. PAM improves soil aggregate cohesion, resisting detachment and dispersion, preserving structure and soil surface roughness. This also maintains pore continuity to the soil surface by preventing dispersion and redeposition of particles that block pores.

Application. The modes of PAM application for erosion control in irrigation are covered in the 2000 U.S. Department of Agriculture–Natural Resource Conservation Service (USDA-NRCS) PAM conservation practice standard. For furrow irrigation, PAM can be dissolved in the water before reaching the furrow, or placed on the soil in the first 1–2 m of the furrow below the water inlet. When PAM is dissolved in the water supply, the best results are obtained at a concentration of 10 ppm PAM as the water first crosses the field, then ceasing PAM application when runoff begins. Placing a dry powder "patch" directly on the soil is the easiest and probably most widely used method. The application rate for the initial patch treatment is an area equivalent rate (based on furrow spacing and length) of 1–2 lb/acre. A variation on the patch is use of PAM tablets in the furrow. However, the tablets sometimes dissolve erratically. On nearly level fields (slopes <0.2%), continuous application of 1 ppm PAM works well. For all methods, if the soil remains undisturbed after initial PAM treatment, subsequent irrigation usually requires half (or less) the initial PAM concentration applied. Season-long erosion control for irrigation furrows can usually be achieved using 3–5 lb of PAM per acre. Sprinkler irrigation wets a larger soil area than furrow irrigation and involves splash. PAM in an equivalent water application depth of 18–20 mm (3/4 in.) at a rate of 2–4 kg/hectare (2–4 lb/acre) controls sprinkler-induced erosion. Season-long control with sprinklers requires continued PAM application until canopy coverage;

however, application rates of subsequent irrigations can be greatly reduced.

Because soil surface structure is kept porous when using PAM, infiltration rates are generally higher with PAM-treated water on fine to medium-textured soils (clays and loams). Farmers can use PAM to improve infiltration precision and uniformity in surface and sprinkler irrigation systems and reduce runoff and runon problems. In many settings, the infiltration management potential is a greater incentive than erosion control to adopt PAM use.

Environmental restrictions. Soil amendment registrations, environmental regulations, and USDA-NRCS guidelines restrict erosion-control PAMs to anionic forms containing <0.05% unreacted acrylamide monomer (AMD). Neutral or cationic PAMs can harm certain microorganisms or aquatic species. Cationic PAMs adhere to hemoglobin-bearing fish gills, causing suffocation. Anionics are safe at (and well beyond) the prescribed erosion-controlling concentration. Acrylamide monomer, a neurotoxin, poses no health or environmental risk at the rates and concentrations specified, and it is removed rapidly from the environment (hours to days) by microorganisms. High-purity anionic PAMs are used in municipal water treatment, food processing and packaging, pharmaceutics, and animal feeds. Erosion control represents 1-2% of PAMs or related polymers used annually in the United States for paper manufacture, mining, and sewage treatment.

Environmental benefits. The environmental benefits of PAM-based erosion prevention are well documented. PAM reduces nitrogen and phosphorus (eutrophying nutrients), biological oxygen demand (BOD), and several herbicides and pesticides by 60-80% in runoff water. Since 1998, 10-20 million tons of sediment, thousands of tons of nutrients, and hundreds of tons of herbicides and pesticides per year have been prevented from entering riparian (wildlife-supporting) waters. Recent research has shown large reductions in weed seed and microorganism loads in PAM-treated runoff. Sequestration of weed seed and microbes reduces the spread of weeds and crop diseases within and among fields, reducing their impact on crop production and lowering the need for herbicides and pesticides. Because fecal coliforms and other human hygiene-impacting microorganisms enter surface water from manure-treated fields, microbe sequestration via PAM also reduces organism-related human health threats.

Extension of PAM technology to rain-fed agriculture is difficult and may not prove economical or effective on a wide scale for various physical, chemical, and logistical reasons. However, PAM use for construction site, road cut, and mine site erosion control and for accelerating water clarification in runoff retention ponds has increased rapidly. PAM and other organic and synthetic polymer-based erosion-control and water quality-protection technologies will likely continue to improve and be implemented in the future.

For background information *see* EROSION; IRRIGATION (AGRICULTURE); POLYACRYLONITRILE RESINS; SOIL CONSERVATION; WATER POLLUTION in the McGraw-Hill Encyclopedia of Science & Technology.

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Soil quality

Soil—the thin, unconsolidated, vertically differentiated portion of the Earth's surface—is ubiquitous and often ignored despite its many important environmental and life-sustaining functions. Soil is necessary for the production of food, feed, and fiber products, and supports buildings, roads, and playing fields. Soil helps to safely dispose of and process biological and industrial wastes, and it purifies and filters water that may enter drinking water supplies. Usually, soil performs more than one of these roles simultaneously.

Soil is in large but finite supply. It varies greatly in chemical and physical properties both in short distances and regionally. Some soil components cannot be easily renewed within a human time frame; thus the condition of soil in agriculture and the environment is an issue of global concern. For these reasons, an effort has been made to distinguish among the many kinds of soils and identify those best suited for specific uses. The concept of soil quality stems from the desire to evaluate soils, match appropriate management and uses for each soil, and measure changes in soil properties.

Concept. The concept of soil quality has been controversial among soil scientists because it is subjective, as well as being management- and climate-dependent. The concept has not been thoroughly tested by the scientific community, but it has been institutionalized by some government agencies despite the scientific discord surrounding it. In contrast, concepts of air and water quality are well accepted. It may seem reasonable to include soil quality as a basic

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